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Possibility of Crowdsourcing-based Method for Surveying the Flatness of Pedestrian Spaces

Jung Il Shin [1], Jung Ok Kim [2]

[1] Division of Digital City Research, Seoul Institute, Seoul, Korea - jishin@si.re.kr
[2] Division of Strategic Research, Seoul Institute, Seoul, Korea - jungok@si.re.kr

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Abstract

A detailed investigation of walking spaces is essential for ensuring the safety of mobility-impaired pedestrians because the conditions of walking spaces affect the daily lives. Seoul Metropolitan Government is exploring barrier-free policies and the Seoul universal design guidelines define the structure of pedestrian spaces. However, these guidelines apply to only a few representative pedestrian-friendly areas or public institutions, causing mobility-impaired people to experience restrictions in other areas. This study propose possibility to investigate condition of pedestrian space using smartphones and strollers with a crowdsourcing model. A smartphone was attached to the cup holder of a stroller to acquire data during its drive through a residential complex. While the stroller was driving, acceleration, rotation, location, and photo data were obtained using a free app installed on a smartphone. As a result of experiment, the acquired data showed different variations in linear acceleration depending on the roughness of the surface. When there was a slope, there was a change in the vertical angular. Therefore, possibility was determined to investigate the flatness of the walking space using a smart device and a four-wheeled vehicle. Additionally, a crowdsourcing model was proposed to survey the entire city in a short period of time. This model includes providing highly feasible rewards to increase citizen participation in surveys.

1. Introduction

The conditions of walking spaces significantly impact the daily lives of pedestrians with disabilities. For instance, the width and slope of walking paths determine the possibility of wheelchair movements, and flatness determines the movement quality. Furthermore, the appropriate location and shape of braille blocks are crucial for ensuring the safety of visually impaired pedestrians. Therefore, a detailed investigation of walking spaces is essential for ensuring the safety and accessibility for mobility-impaired pedestrians. Without a thorough understanding and regular monitoring of these spaces, the daily lives of many people could be severely restricted, leading to increased isolation and decreased quality of life.

In existing approaches, many indices for evaluating walkability have been created, each containing some terminology related to walkability in tools or checklists to assess walkability in pedestrian environments through field surveys and questionnaires (Campisi et al., 2021). These environmental audits and subjective evaluation methods have obvious advantages in terms of approximating reality, but there are limitations in terms of cost, time, and measurement scale. Additionally, it is challenging to verify the effectiveness of these methods in controlled experiments. For instance, Guensler et al. (2015) installed a tablet personal computer on a wheelchair using sensors such as a built-in accelerometer, gyro, and camera, to investigate the obstacles during its movement. They used the data collected to build an online system for analyzing the sidewalk width, longitudinal slope, steps, obstacles, and flatness. Similarly, Ignaccolo et al. (2020) defined factors for evaluating street walking conditions and proposed the Pedestrian Compatibility Index (PCI) using a walking environment survey database and spatial analysis techniques.

Seoul Metropolitan Government is actively promoting barrier-free policies, such as “Accompanying the Weak” and “Seoul, a Walking City.” Furthermore, the Seoul universal design guidelines define the structure of pedestrian spaces considering the movement of wheelchairs, specifying standards for curb height, chamfer, and longitudinal and transverse slopes of the pedestrian space (Go et al., 2017). However, these guidelines are currently applied only to a few representative pedestrian-friendly areas or public institutions, causing mobility-impaired people to experience restrictions in other areas. Although curb height and chamfers are appropriately implemented throughout Seoul, the road surface slope, roughness, and flatness are not considered for policy establishment due to the lack of measured data. This gap in policy implementation highlights the need for more comprehensive and inclusive data collection methods.

Presently, Seoul City identifies improvement needs through civil complaints and conducts human-centered surveys using visual inspection and simple measurement methods. However, these approaches are time-consuming and expensive when investigating the conditions of pedestrian spaces throughout the entire city. This highlights the need for an efficient and scalable method to investigate the status of pedestrian spaces. A promising solution is to leverage crowdsourcing using smart devices and moving objects. Crowdsourcing can harness the collective effort of a large number of individuals, enabling the rapid collection of vast amounts of data across wide areas. By involving citizens in the data collection process, it would be possible more detailed and extensive mapping of pedestrian space conditions.

The goal of this study is to explore the possibility of investigating the flatness of pedestrian spaces using smart devices and moving objects, and to propose a crowdsourcing model capable of surveying an entire city in a short period. By utilizing the sensors available in smartphones, such as accelerometers, gyroscopes, and GPS, ordinary citizens can contribute valuable data regarding the condition of pedestrian pathways.

2. Methods

2.1 Study Area

The study area is a pedestrian space in an apartment complex in Nowon-gu, Seoul, South Korea. Figure 1 shows the study area and moved path displayed on S-Map, Seoul's digital twin. The path begins in the building lobby paved with marble and continues in the following order: a slope paved with tiles, a sidewalk paved with blocks, and a road paved with asphalt. There are located manholes, speed bumps, and slopes along the path. Figure 2 shows the pavement materials distributed along the travel route.

Although the study area is private space, it has characteristics similar to public pedestrian spaces and represents a pedestrian space where universal design has not been applied. When people go out to public places, the first thing they see is the pedestrian space in front of their houses. Therefore, if the walking space in front of the house is in poor condition, there is a high possibility that the movement of people with mobility impairments will be restricted.

Figure 1. Study area and movement path presented on Seoul's digital twin (S-Map).

Figure 2. Type of surface pavement along the path (top left: marble, top right: tiles, bottom left: blocks, bottom right: asphalt).

2.2 Data Acquisition

Crowdsourcing-based data collection requires very simple and popular equipment. The equipment used was a stroller and a smartphone. The stroller's wheels have no cushions and the handle has a cup holder. The smartphone was placed vertically in the cup holder, and paper was placed in the empty space to prevent shaking unrelated to the road surface condition (Figure 3).

Figure 3. Stroller and installed smartphone used to measure surface conditions of pedestrian space.

To acquire data, a free app (Sensor Logger version 1.31.3, Tszheichoi) was installed on the smartphone. This app collects kinematic data at approximately 100 Hz using sensors, such as gravitational accelerometer, linear accelerometer, magnetometer, gyroscope, and global positioning system (GPS), built into the smartphone. The collected data included time (millisecond), gravitational acceleration (gFx, gFy, and gFz), linear acceleration (ax, ay, and az), angular velocity (wx, wy, and wz), rotation (azimuth, pitch, and roll). Location (latitude, longitude) and photos are acquired every second.

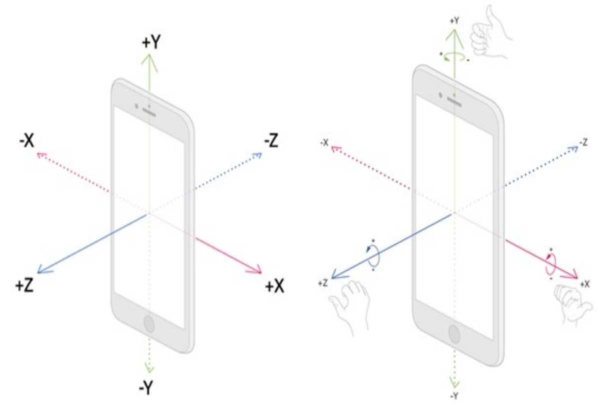

Figure 3. Reference axis and direction for acceleration and rotation measurements (Tszheichoi, 2024).

Figure 4 depicts the z-axis linear acceleration (az) as an example; the six grades classified by the natural Jenks classifier are expressed in colors. Because the measurement started indoors and passed between tall buildings, there was a high positional error in the initial section, but the flatness along the path could be easily determined by colors.

Figure 4. Z-axis linear acceleration (m/s^2) classified into six grades and expressed in colors.

3. Results and Discussion

3.1 Data Pattern by Surface Condition

The pattern of factors among the acquired data was visually analyzed to determine whether the condition (roughness and slope) of the walking surface could be identified. As a result, the variation of linear acceleration appeared in different patterns depending on the roughness of the surface. Among the three axes, Z-axis linear acceleration (az) showed the clearest pattern. Among the measurement parameters, the Y-axis angular velocity showed a clear pattern with slope.

Figure 5 shows the Z-axis linear acceleration and Y-axis angular velocity over time (second) in a section where the surface is flat marble and sloped tile. In the case of the marble section, since the surface is very smooth, the variation of Z-axis linear acceleration is about 0 m/s^2. It can be seen that variation increases to ±2-3 m/s^2 on the tile section, which is interpreted as being caused by the gap between tiles, although the surface of the tile itself is smooth. The Y-axis angular velocity shows a value close to 0 rad/s on mean in the flat marble section, and the value increased in the negative direction in the tile section with a downward slope. At the end of the tile section, the Y-axis angular velocity increases in the positive direction where the slope ends and the flat surface begins.

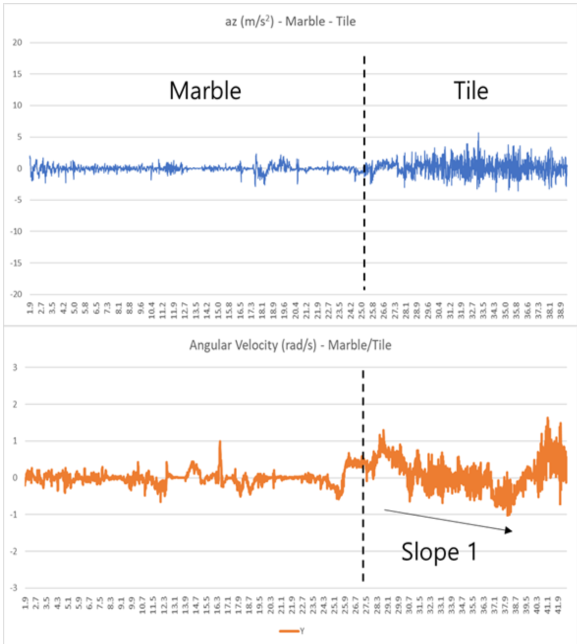

Figure 5. Z-axis linear acceleration (m/s^2) and Y-axis angular velocity(rad/s) on flat marble and sloped tile surface.

Figure 6 shows the Z-axis linear acceleration and Y-axis angular velocity in a section paved with blocks. It can be seen that the variation in Z-axis linear acceleration has increased to about ±5-7 m/s^2. Among three manholes in the section, the first and second have height difference from the surface, and it can be seen that the variation in Z-axis linear acceleration increases significantly. On the other hand, the third manhole shows variation close to 0 m/s^2 due to smooth surface and no height difference. The change in the mean Y-axis angular velocity according to the slope showed a pattern of gently decreasing and then increasing on slope 2 and rapidly decreasing on slope 3. The reason is that slope 2 slopes gently down and then up, and slope 3 is down to the road and has a curb with height difference at the end.

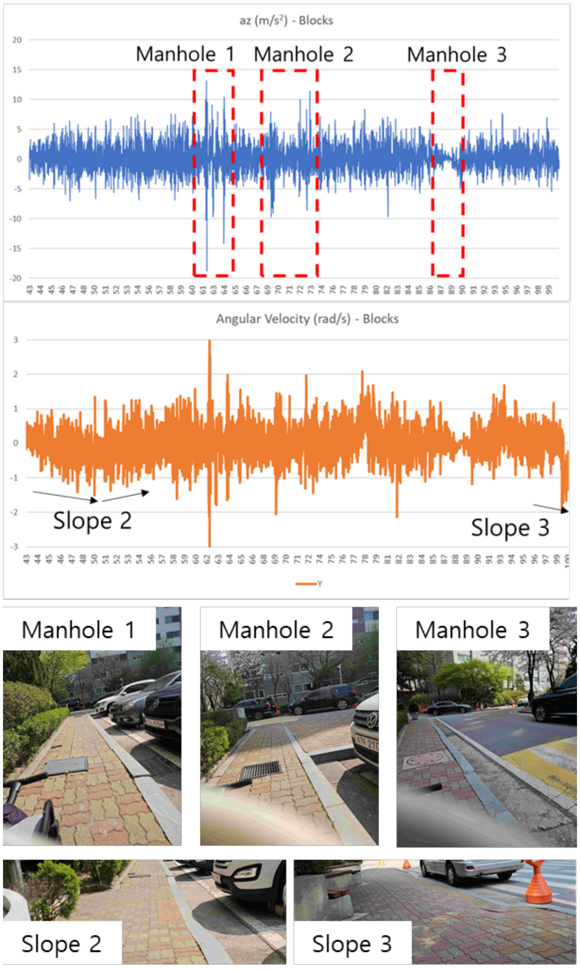

Figure 6. Z-axis linear acceleration (m/s^2) and Y-axis angular velocity(rad/s) on sidewalk paved with blocks where is located manholes and slopes.

Figure 7 shows the Z-axis linear acceleration and Y-axis angular velocity on an asphalt road. Asphalt pavement is a smooth surface and shows an acceleration variation of ±1-2 m/s^2. The variation increases at the speed bump in the middle and the slope 5 at the end. The speed bump has gentle change in slope, so the variation is not large, but the slope connecting the road and sidewalk shows relatively large variation. Y-axis angular velocity shows a downward pattern on slope 4 at the beginning of the road, and an upward pattern on the slope leading up to the sidewalk.

The measured linear acceleration and angular velocity showed patterns for road surface roughness, obstacles, and slope. As the road surface became rougher, the variation in linear acceleration increased, and the mean of angular velocity changed in the slope. It was seen that the variation in linear acceleration and angular velocity increased at points where obstacles with height difference. Therefore, the roughness, slope, and height difference of the pedestrian space can be identified using acceleration and rotation data.

In the future, the correlation of these factors must be analyzed with respect to quantitative measurements of road surface conditions. A model must be developed to quantitatively measure the road surface roughness, slope, and level changes considering the characteristics of moving objects, such as wheel size, tires, and cushions, along with the characteristics of the built-in sensors of smart devices. This model should be applied to various conditions and environments of crowdsourcing.

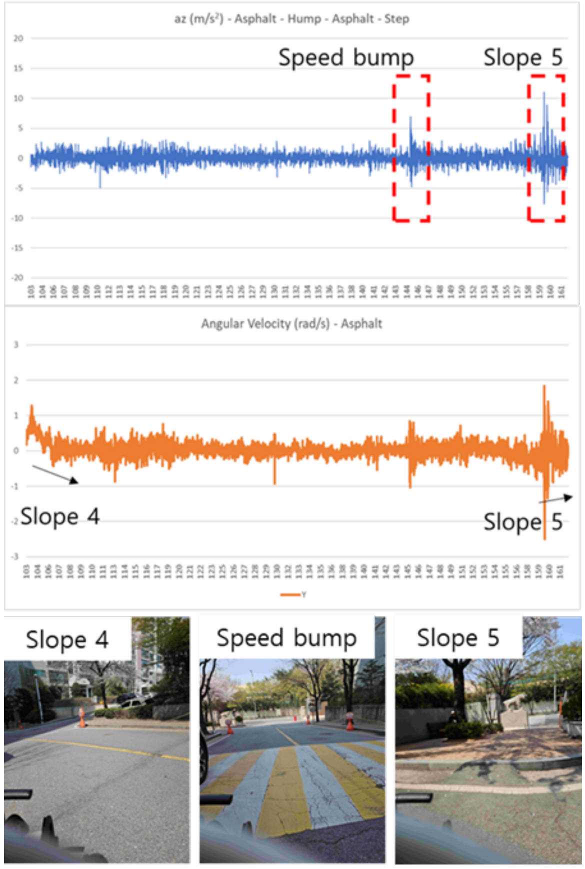

Figure 7. Z-axis linear acceleration (m/s^2) and Y-axis angular velocity(rad/s) on asphalt road where is located a speed bump and slopes.

3.2 Crowdsourcing Model

The area of Seoul is approximately 605 km^2 and the population is approximately 10 million. Statistical data shows that the length of sidewalks is approximately 1.7 million meters and the area is approximately 7 million square meters. However, in many cases the pedestrian space is not separated from the roadway, making accurate estimation difficult. Surveying pedestrian spaces throughout Seoul requires a lot of budget and time, so a smart method that can efficiently survey in a short period of time is needed.

In this study, a crowdsourcing model is proposed to investigate surface conditions in pedestrian spaces (Figure 8). This model begins with data acquisition by citizens with smart devices and four-wheeled vehicles. The acquired data is transmitted to the system via Wi-Fi. The transmitted data is accumulated, processed, and analyzed in the system, and output in the form of reports and maps are produced. Through the report, public officials can identify priorities for areas to improve pedestrian space, and citizens can use maps to guide comfortable travel routes. Additionally, this model has a cyclical structure that increases participation by providing rewards to citizens who provide data.

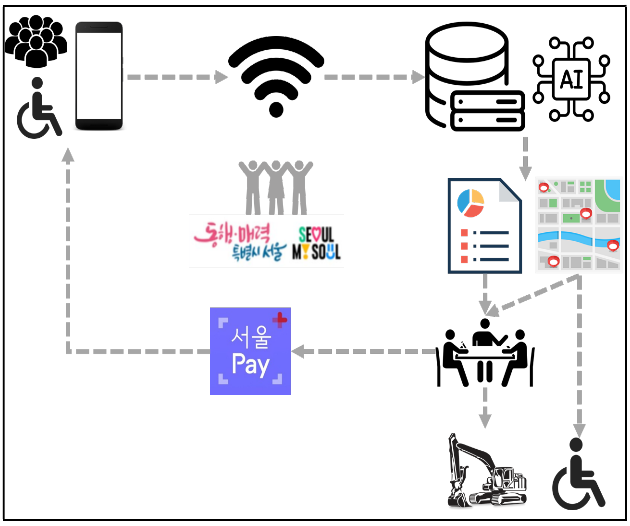

Figure 8. Proposed crowdsourcing model to survey surface condition of pedestrian space.

In the proposed model, the components that require budget are communication for data transmission, system construction, and rewards. In order to maximize citizen participation, it is necessary to allocate a large budget to rewards and minimize the budget for communication and system construction.
Communication costs can be minimized by using public Wi-Fi operated by Seoul City. The city of Seoul operates approximately 14,000 public Wi-Fi zones, and free Wi-Fi is available on all public transportation. Therefore, there is a need to develop a survey app that has the function of automatically transmitting data when citizens can use free Wi-Fi.
Development costs can be minimized by including the system as part of a Seoul smart city platform under development (Figure 9). The platform consists of various transportation-related systems such as road surface scanning, on-demand transportation, pedestrian space scanning, and smart CCTV. The currently planned pedestrian space scanning system has the purpose of monitoring illegal parking and dumping, but since it targets the same space, it is believed that the function of collecting, processing, and analyzing road surface condition data in the pedestrian space can be added.

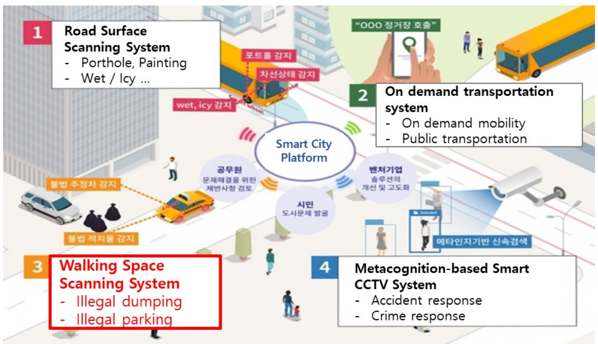

Figure 9. System configuration of the Seoul Smart City platform under development.

Rewards can be provided using Seoul Pay, a local prepaid coupon operated by the Seoul Metropolitan Government (Figure 10). This method has already been used in other campaigns which called Wrist Doctor 9988. Citizens set goals and receive rewards through Seoul Pay based on the number of steps measured with their smartphones. It is a welfare policy that allows Seoul citizens to improve their health and receive rewards of up to 70 euros per year. Therefore, the idea of using Seoul Pay to increase participation in crowdsourcing for pedestrian space survey appears to be highly feasible.

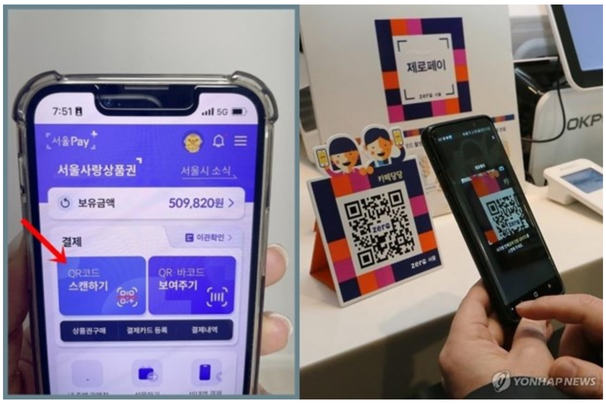

Figure 10. Seoul Pay, a local prepaid coupon operated by the Seoul Metropolitan Government.

4. Conclusions

In this study, we examined the possibility of implementing crowdsourcing-based surveys using mobility and smart devices to investigate the surface condition of pedestrian spaces. An initial experiment was performed by mounting a smartphone on a stroller to determine the road surface conditions in the walking space. The acceleration and rotation data collected using the built-in sensors of the smartphone showed patterns with the roughness, slope, and level difference of the surface.
A crowdsourcing model to survey the surface condition was proposed. Crowdsourcing is a smart way to simultaneously survey urban pedestrian spaces. Rewards are needed to increase citizen participation in crowdsourcing, and Seoul City already has a successful case. In addition, a plan to minimize the data transmission and system development budget was presented to secure the budget for rewards.
This method not only reduces the time and cost associated with traditional survey techniques but also allows for real-time updates and a more comprehensive understanding of the pedestrian environment. Ultimately, the findings from this research aim to provide insights that can assist city planners and policymakers in making informed decisions to enhance the accessibility and safety of urban walking spaces for all citizens.
In further study, there is a need to quantitatively improve the patterns of visually analyzed data. Additionally, quantitative studies are needed with various moving objects, smart devices, and surface condition and it is necessary to apply to the crowdsourcing method. Efforts are needed to make the crowdsourcing model more specific and reflect it in policy.

Acknowledgements

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